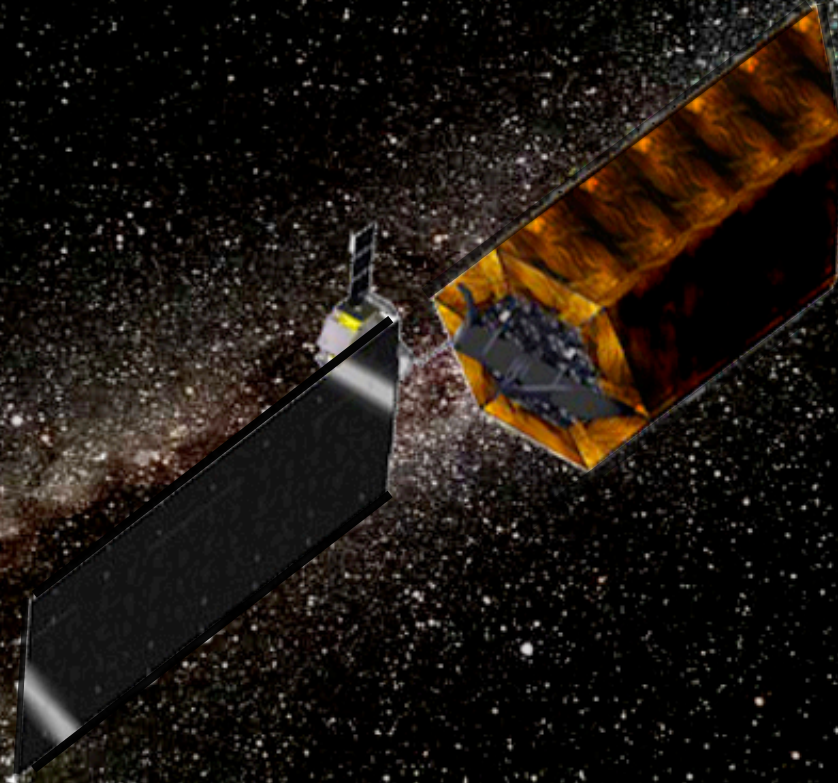


An Advanced Technology Large-Aperture Space Telescope (ATLAST): The Roadmap to a Large UV/Optical Space Telescope



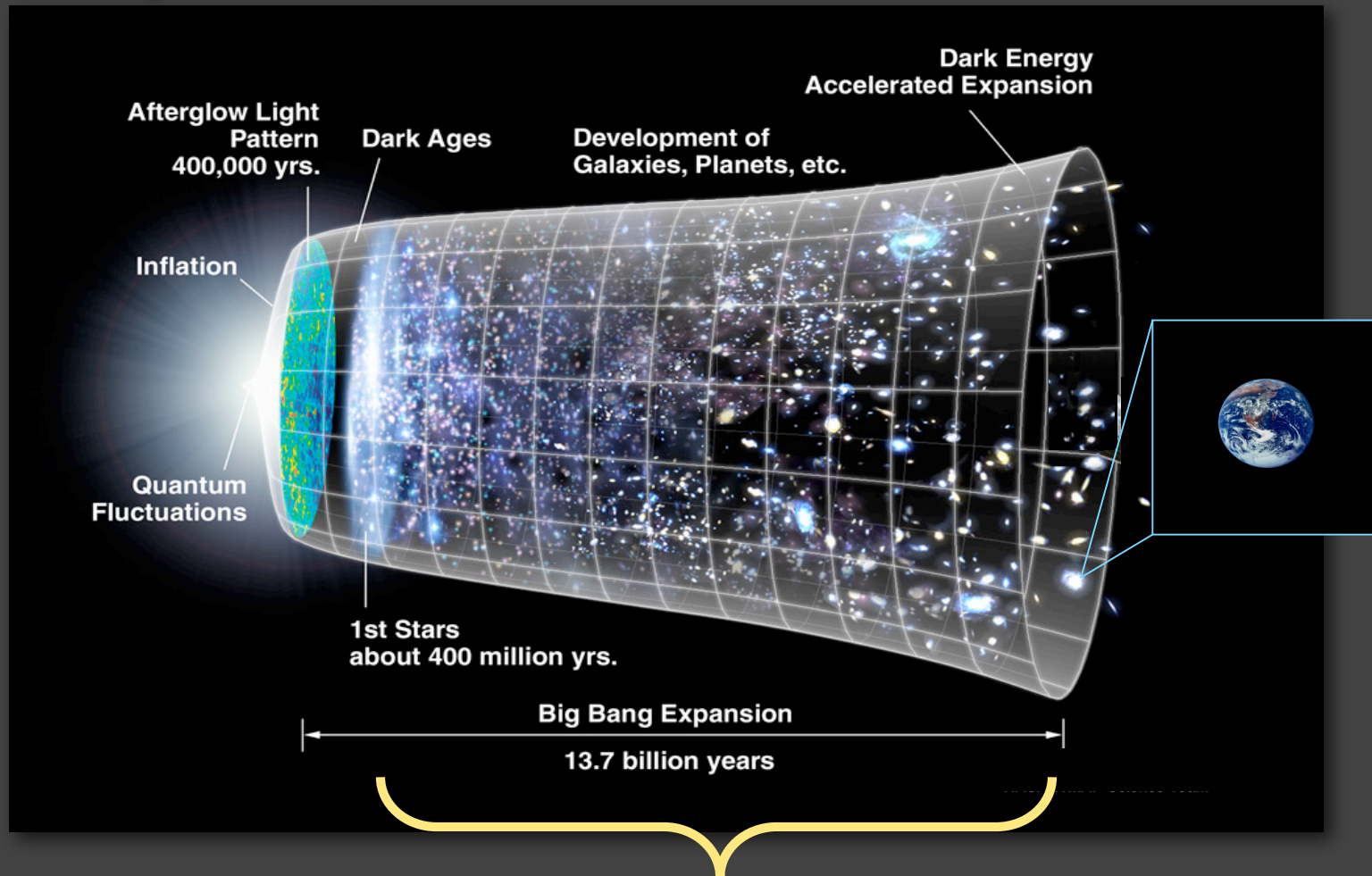
Marc Postman

Space Telescope Science Institute

NASA Ames Ares V Astronomy Workshop

April 27-28, 2008

The story so far, with a few details to fill in...



21st Century astronomers should be uniquely positioned to study “*the evolution of the universe in order to relate causally the physical conditions during the Big Bang to the development of RNA and DNA*”

- Riccardo Giacconi, 1997 (Nobel Prize in Physics 2002)

The Imperative for a larger UV/Optical Space Telescope

How did the present Universe come into existence and what is it made of?

- How do galaxies assemble their stars? What is the standard path to assembling the stellar mass in giant galaxies?
- How does the Intergalactic medium evolve?
- What is the precise relation between the dynamics of baryons and dark matter?

What are the fundamental components that govern the formation of today's galaxies?

- How do super massive black holes evolve?
- Why is their mass correlated with that of their host galaxies?

How does the Solar System work?

- What are the connections between the Solar System's Interplanetary Medium and the Local Interstellar medium?
- What are the physical processes driving the weather on the outer gas giant planets in the Solar System?

What are the conditions for planet formation and the emergence of life?

- What fraction of circumstellar disks form planets?
- Are there detectable biosignatures on exoplanets in the Habitable Zones of their host stars?

ATLAS Telescope: Technology Roadmap

NASA Astrophysics Strategic Mission Concept Study Team

Ball Aerospace:

Vic Argabright Teri Hanson
Paul Atcheson Leela Hill
Morley Blouke Steve Kilston
Dennis Ebbets

JPL:

Peter Eisenhardt Dave Redding
Greg Hickey Karl Stapelfeldt
Bob Korechoff Wes Traub
John Krist Steve Unwin
Jeff Booth Michael Werner

STScI:

Tom Brown Marc Postman, P.I.
Rodger Doxsey Neill Reid
Andrew Fruchter Kailash Sahu
Ian Jordan Babak Saif
Anton Koekemoer Ken Sembach
Peter McCullough Jeff Valenti
Matt Mountain

Goddard Space Flight Center:

David Aronstein Rick Lyon
Lisa Callahan Gary Mosier
Mark Clampin Bill Oegerle
David Content Bert Pasquale
Qian Gong George Sonneborn
Ted Gull Richard Wesenberg
Tupper Hyde Jennifer Wiseman
Dave Leckrone Bruce Woodgate

Johnson Space Flight Center:

John Grunsfeld

Marshall Space Flight Center:

Bill Arnold Phil Stahl
Randall Hopkins Gary Thronton
John Hraba Scott Smith

University of California:

Steve Beckwith

University of Colorado:

Webster Cash Mike Shull
Jim Green

University of Massachusetts:

Daniela Calzetti Mauro Giavalisco

Northrop Grumman:

Chuck Lillie Ron Polidan

Princeton University:

Jeremy Kasdin Robert Vanderbei
David Spergel

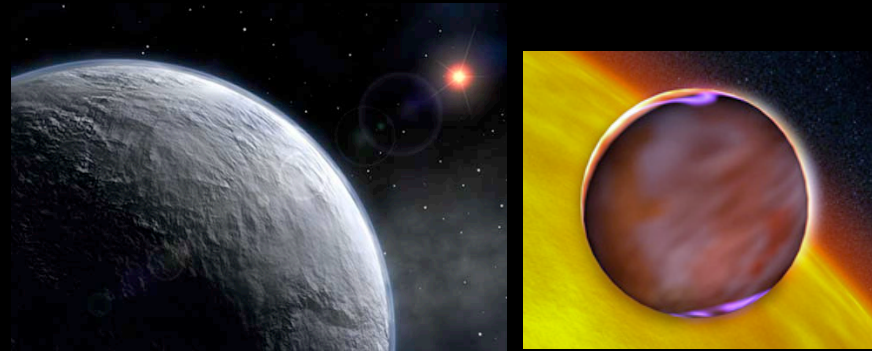


Characterizing Exoplanets

“Does life exist elsewhere in the Galaxy?”

Probes to other planets in the solar system may begin to answer the question. But there are potentially thousands more planets to explore beyond the solar system. The only way to characterize these worlds will be by remote observations.

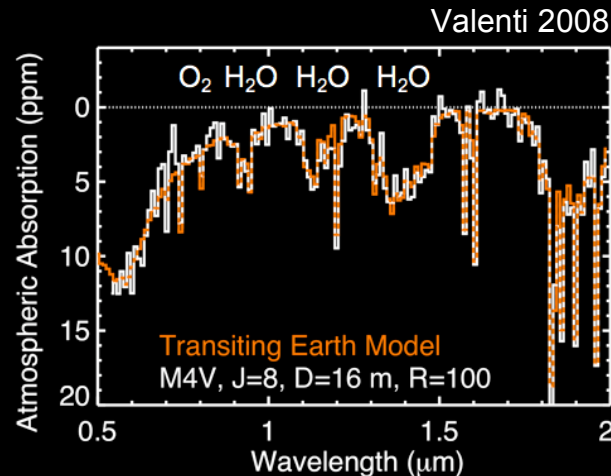
If terrestrial mass ($<10 M_{\text{earth}}$) planets lie within the habitable zones of nearby stars, they may harbor life as we know it. If that life alters the atmospheres of other planets as it has on Earth through the production of oxygen and carbon dioxide, for example, we could detect these chemical signatures in spectra of the planets.



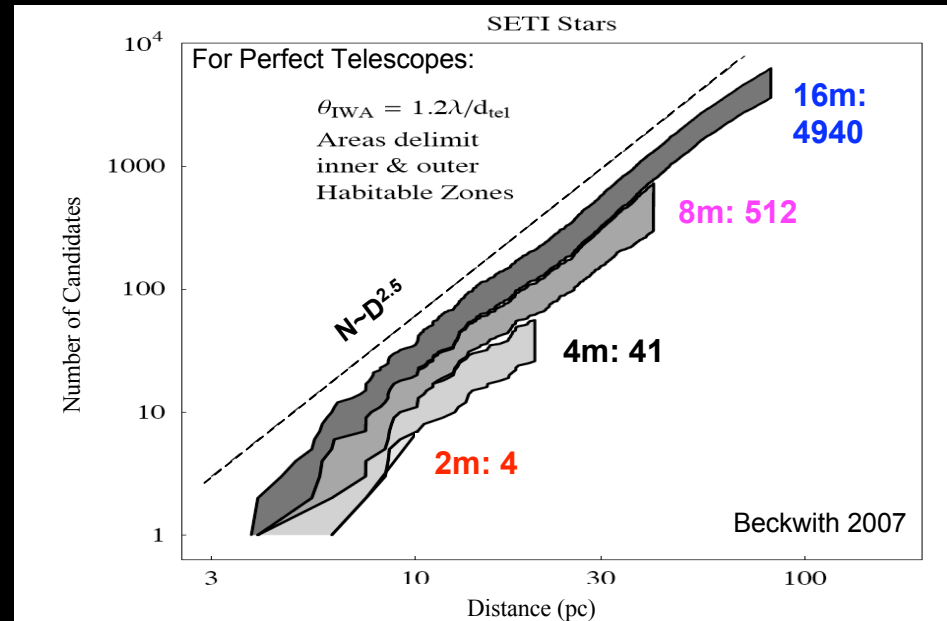
Large space telescopes ($\sim 8\text{-m}$ or more) **are required** to greatly enhance the likelihood of detecting biosignatures from terrestrial exoplanets. This is not a problem that can be addressed even with the largest (20 - 40m) telescopes on the ground due to hard limitations imposed by emission and distortion of light from the Earth's atmosphere (Lunine et al. ExoPTF, 2008).

We require spectra of $\sim 30 m_v$ (< 4 nanoJy) sources: a few photons per second from an exoplanet 10 pc away impinge on the mirror of a large (8 - 16-m) space telescope.

Characterizing Exoplanets



Characterizing Exoplanets: A large space telescope has hundreds (8-m) to thousands (16-m) of candidate stars to search for life's signatures among those with Earth-like planets in the habitable zones, orders of magnitude more than a 4-m telescope for *any* observational technique (See table to right) for both the transit spectroscopy and coronagraphic imaging spectra. The spectra of terrestrial exoplanet atmospheres can be obtained by observing transits (See figure above for 16-m simulation).



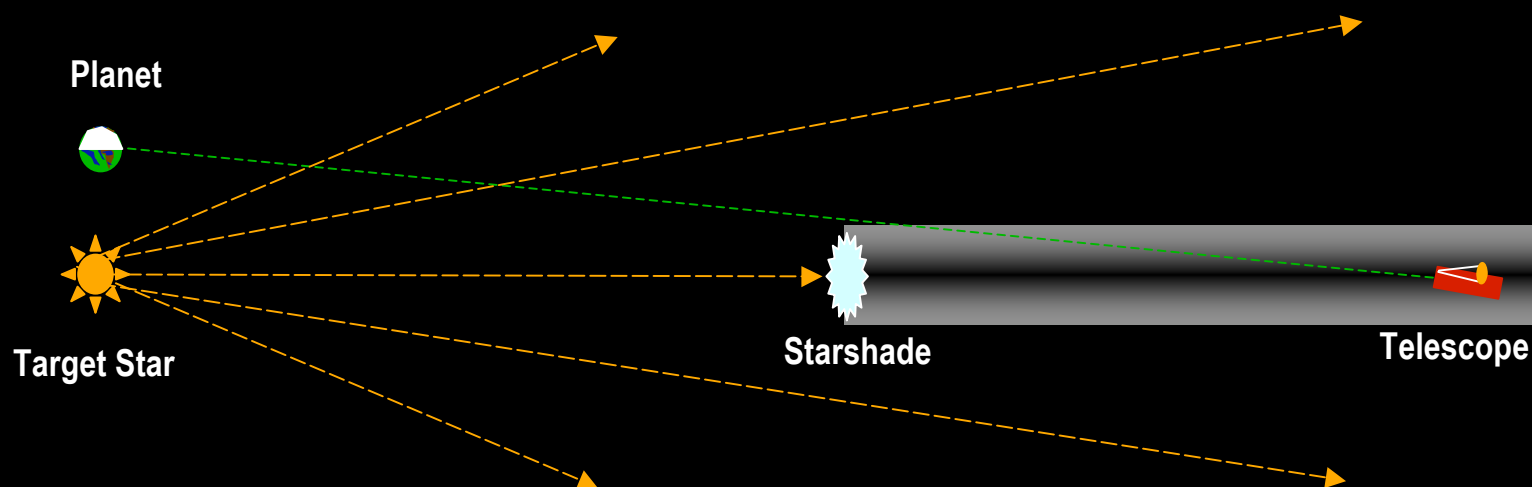
EXOPLANET HOST STAR SAMPLE SIZE vs. TELESCOPE DIAMETER (For Realistic Telescope Performance)			
Primary Mirror Diameter (Meters)	Expected Number of Transits	# Coronagraphic Candidates	
		All Stellar Types	Solar Type Stars
2	0	4	0
4	1	35	13
8	5	280	101
16	40	2240	1417

R = 100, 10 σ , 5 yr

IWA = $3\lambda/D$ @ 1 μm , $\eta = 0.25$,
t = 24h, R = 100

Characterizing Exoplanets

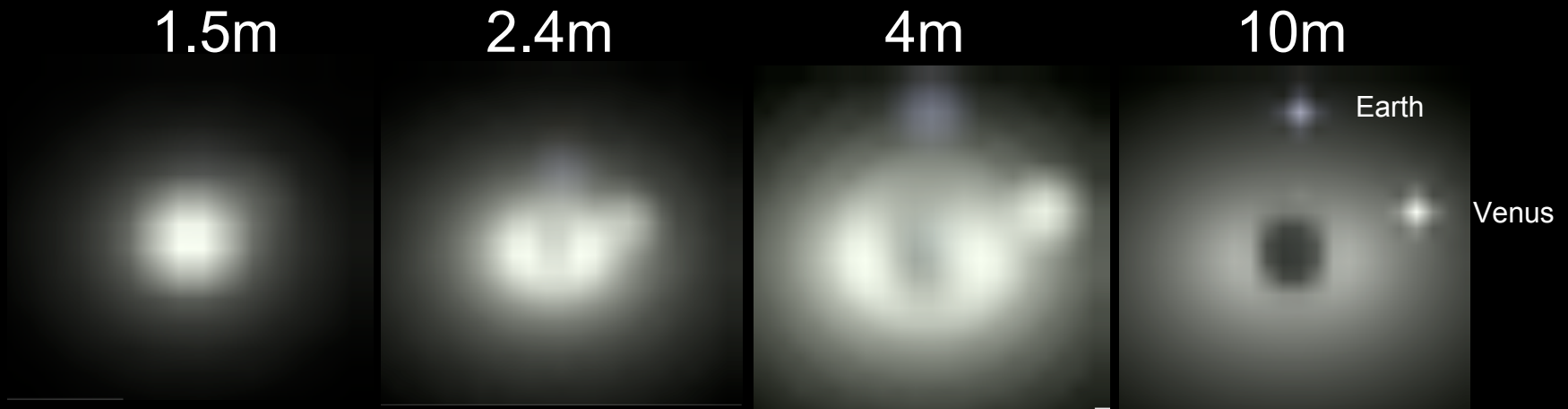
Credit: Web Cash 2008



Characterizing Exoplanets: Via the use of an external occulter, one can suppress the light of the central star, enabling the detection of any orbiting exoplanets. Detecting and characterizing these, however, becomes progressively easier with increasing telescope aperture.

Characterizing Exoplanets

Credit: Web Cash 2008



Above: a simulation of our solar system at a distance of 10 pc observed with an external occulter and a telescope with the indicated aperture size. The two planets are Earth and Venus. The challenges of deploying and maneuvering the star shade, however, also increase with increasing telescope aperture. Using a combination of an internal coronagraph and an external occulter may be the optimal solution.

Characterizing Exoplanets: Via the use of an external occulter, one can suppress the light of the central star, enabling the detection of any orbiting exoplanets. Detecting and characterizing these, however, becomes progressively easier with increasing telescope aperture.

Discriminating terrestrial scale planets from their parent star
also requires angular resolution

Probing Super Massive Black Holes Across Cosmic Time

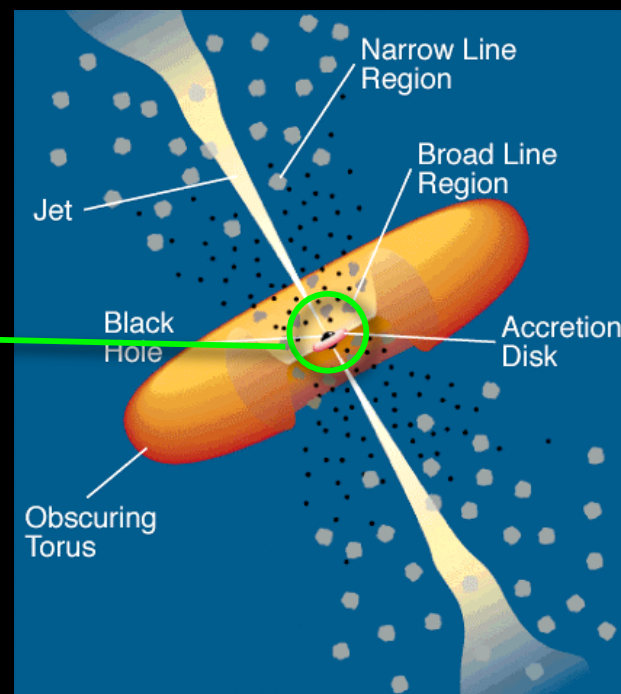
The geometry and distribution of matter immediately around a super massive black hole can be studied using a time resolved UV/optical spectroscopic technique called reverberation mapping.

The very innermost regions of the accretion disk, within a few gravitational radii ($\sim 10^9$ km) of the black hole itself, provide the most direct insight into:

- the properties of the black hole;
- the effects of strong gravitational relativistic forces on the gas falling into the black hole.

These regions are so close to the black hole that they probe light travel times of only a few hours to a few days at most.

To date, only a few local AGN can be studied to this level of detail since high contrast observations are required. For more distant sources, the light from the surrounding galaxy overwhelms the emission from the central source and washes out the signal.



An ATLAS telescope is unique in providing the required combination of:

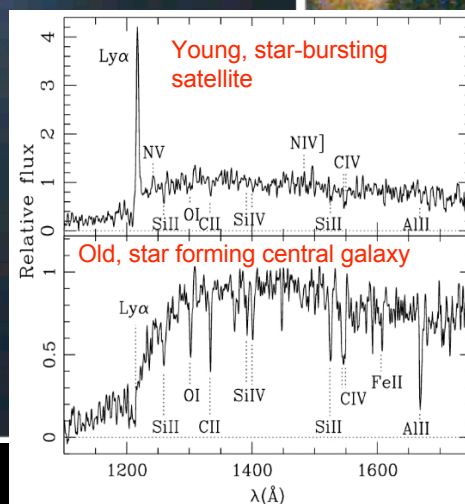
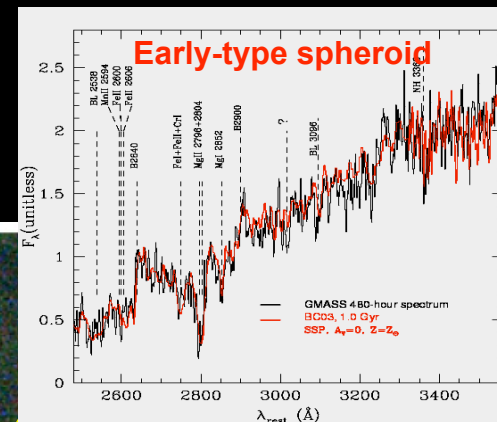
- **high contrast and extensive light-gathering power**

to provide the required high dispersion measurements for black holes well beyond the local universe, up to cosmological distances. ATLAS will also make direct measurements of the mass of high redshift SMBHs.

“Modern” Galaxy Evolution

ATLAST will track how and when galaxies assemble their present stars
ATLAST will investigate why galaxies start to evolve passively.
ATLAST will test the hierarchical formation of structure

We require high ang. resolution & hi-sensitivity access to UV-Vis diagnostics



Galaxy at $z \sim 3$ with HST (100 mas FWHM)

Galaxy at $z \sim 3$ with ATLAST (10 mas FWHM)

A UV/Optical space telescope with an aperture of at least 8-meters and, for some key problems, closer to 16-meters will be required to achieve these ambitious scientific goals.

If λ =Wavelength and D=Telescope Aperture:

Angular Resolution $\propto \lambda/D$

Light Gathering Power $\propto D^2$

Time to achieve a given S/N $\propto D^{-4}$

The Evolving Synergy between Ground and Space Observatories

High angular resolution coupled with high sensitivity is increasingly a science-driven requirement for astronomy.

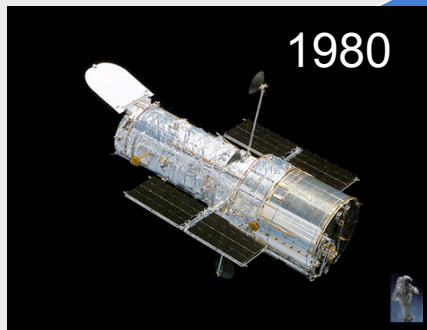
Extremely Large Ground-based Telescopes + next generation MCAO (Adaptive Optics Systems) will redefine the capabilities.

But there remain unassailable advantages of space in the UVO+NIR range. If we want to pursue the compelling scientific issues we imagine today (and the many we cannot imagine), we will need a large UV/Opt space telescope.

Making it affordable is the motivation behind our technology development roadmap for the coming decade.

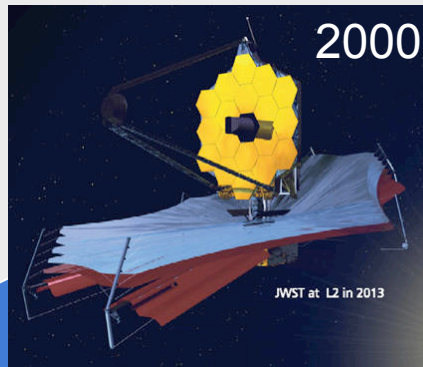
The Challenge

*"Incrementalism is innovation's worst enemy.
We don't want continuous improvement, we
want radical change." - Sam Walton*



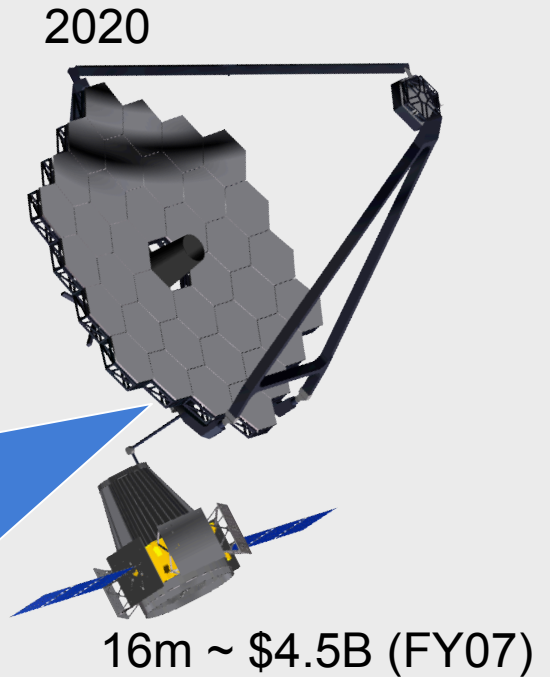
1980

2.4m ~ \$4.5B (FY07)



2000

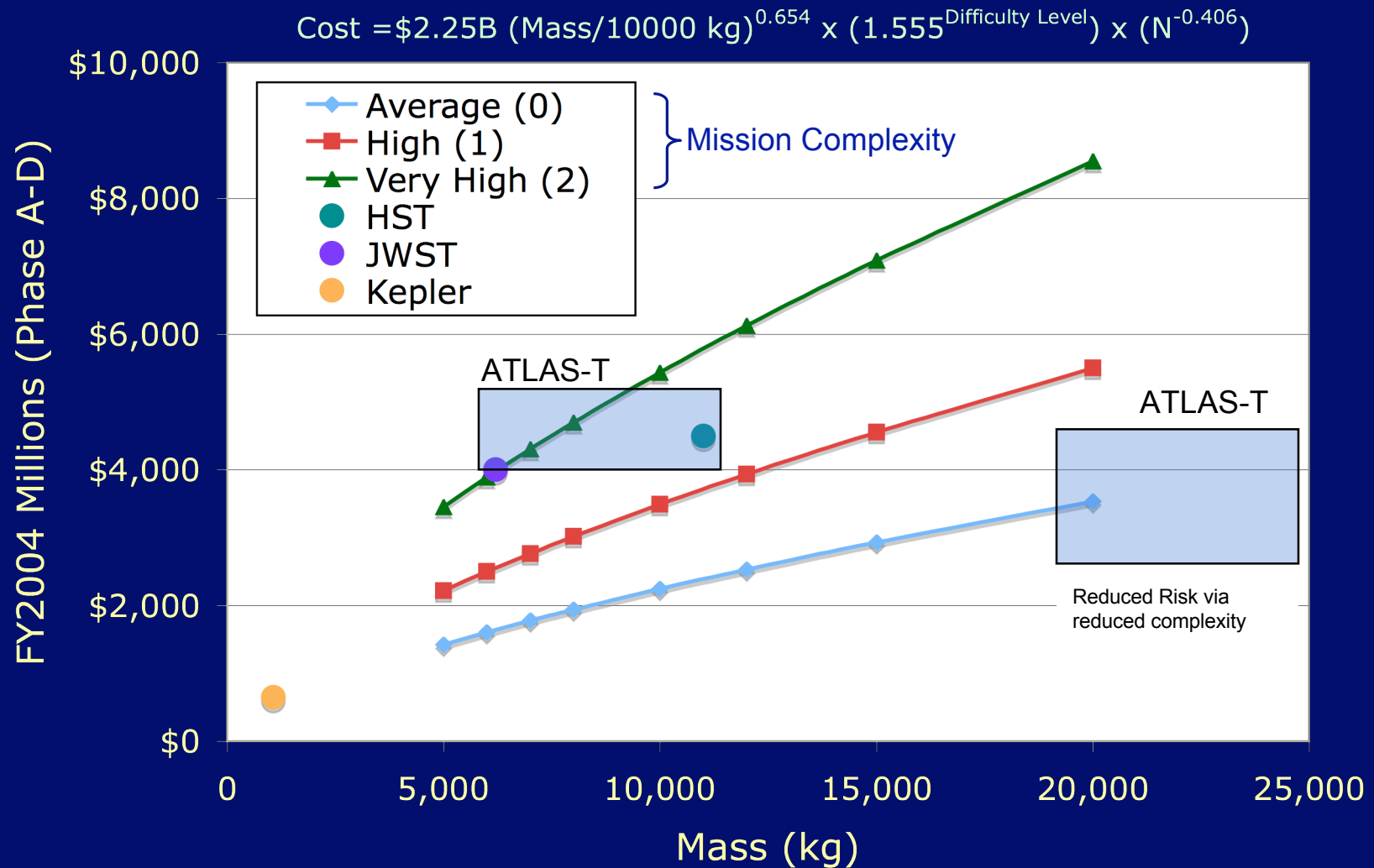
6.5m ~ \$4B (FY07)



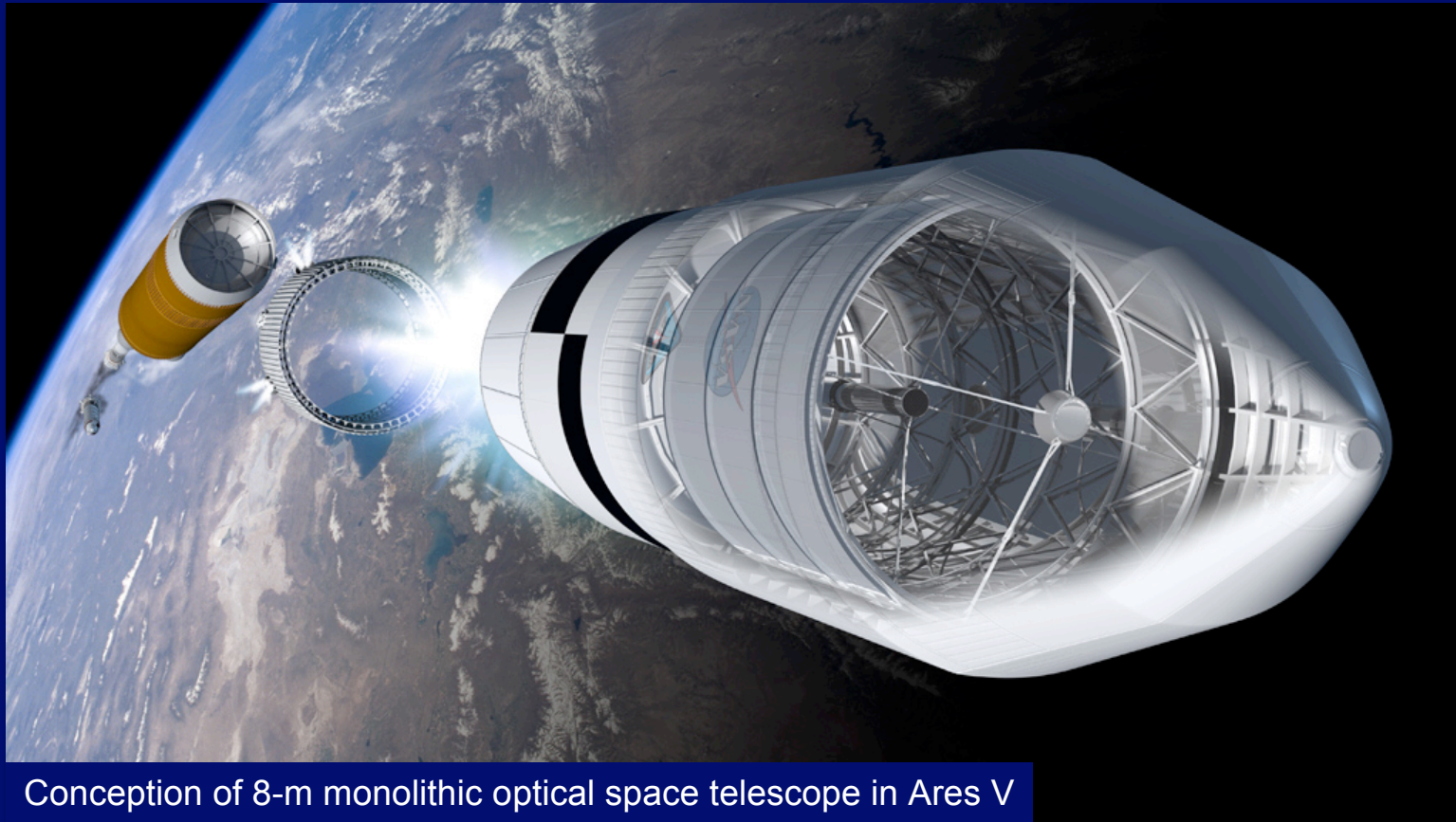
2020

16m ~ \$4.5B (FY07)

Enabling ATLAS-T Technologies: Breaking Cost Curves



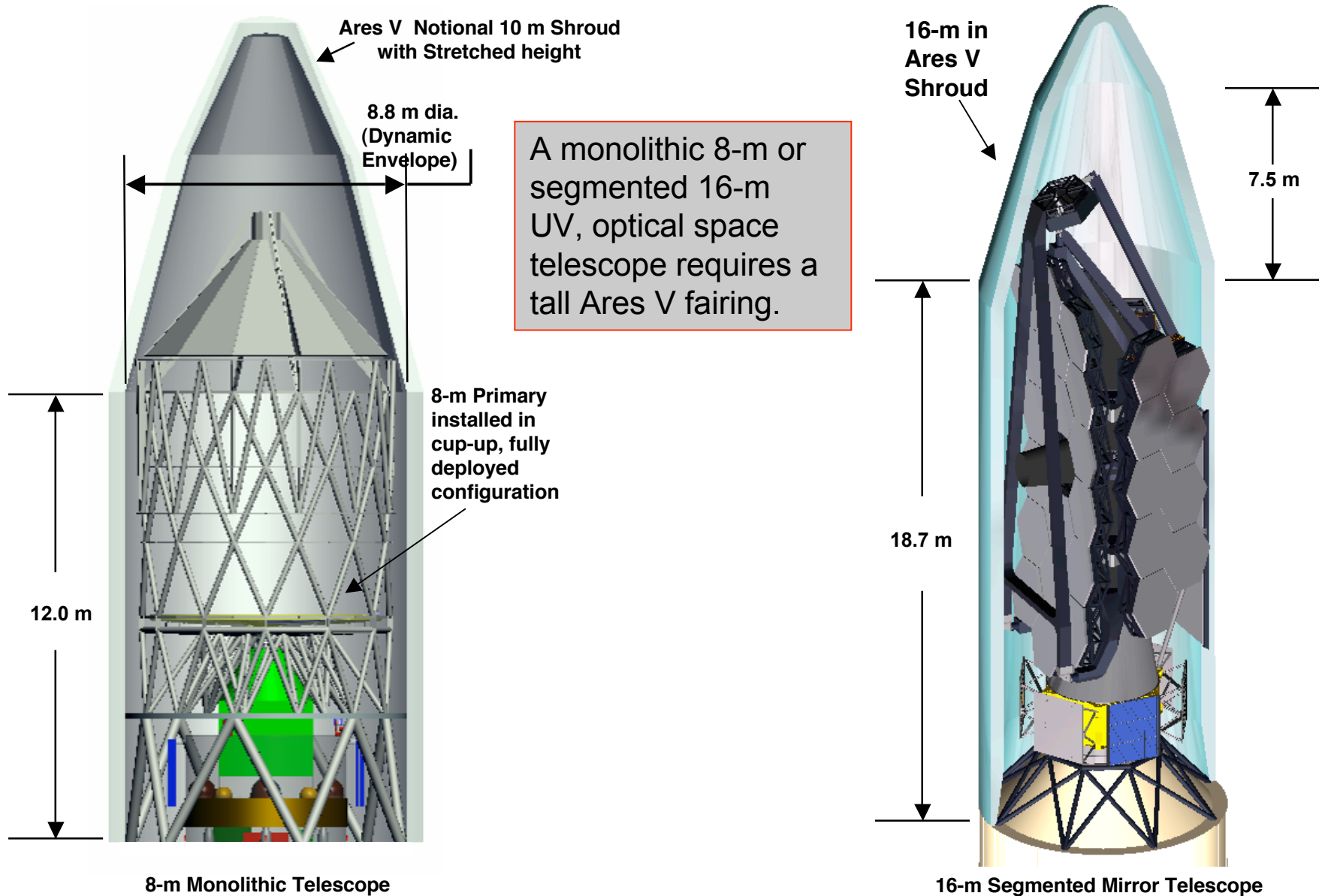
Ares V enables a fully deployed 8-m or folded, segmented 15 - 20m telescope to be deployed in a single launch.



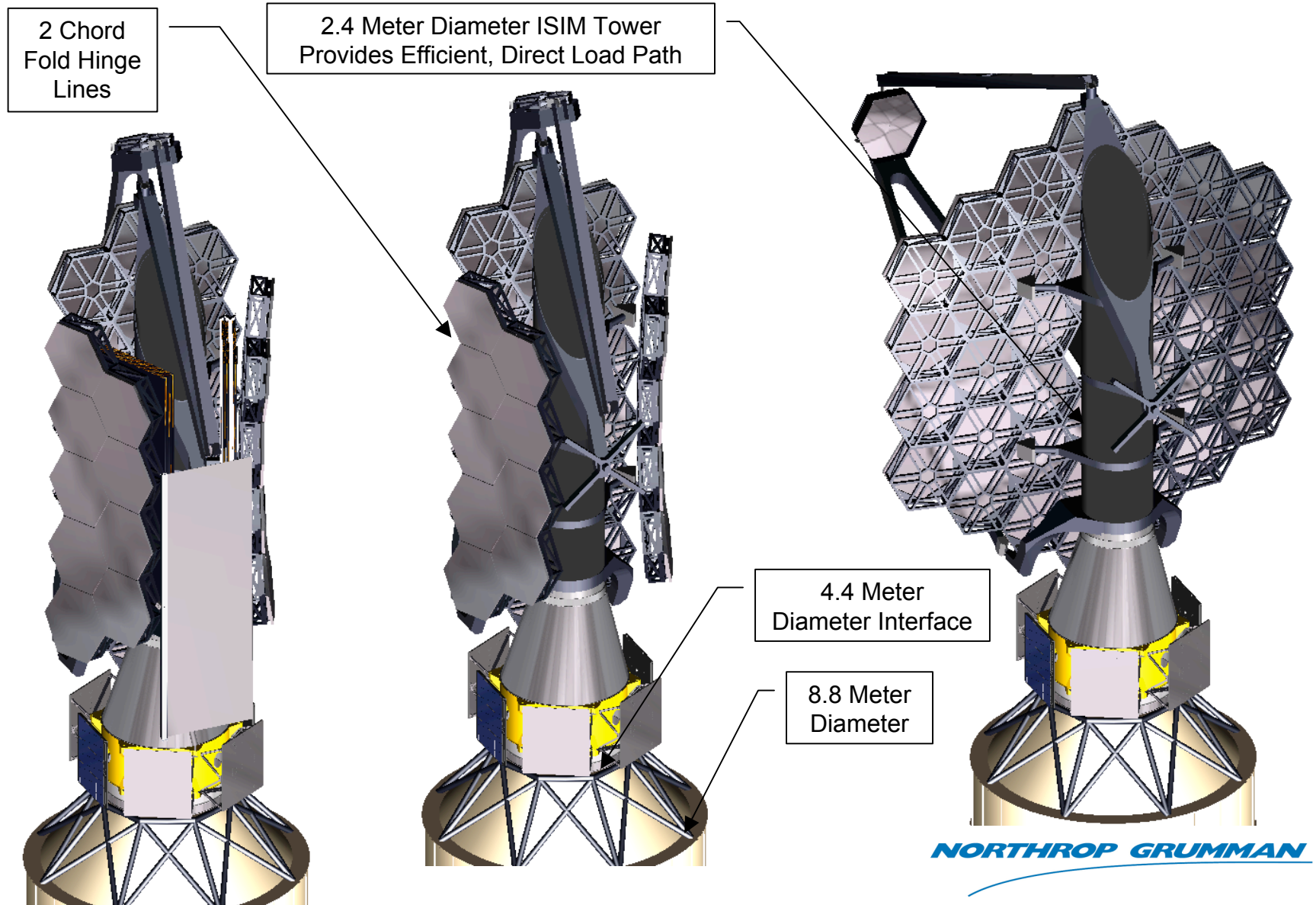
Conception of 8-m monolithic optical space telescope in Ares V

Without Ares V, multiple launches, complex folded optics, and/or on-orbit assembly would be the only alternatives for deploying space telescopes larger than ~7-m.

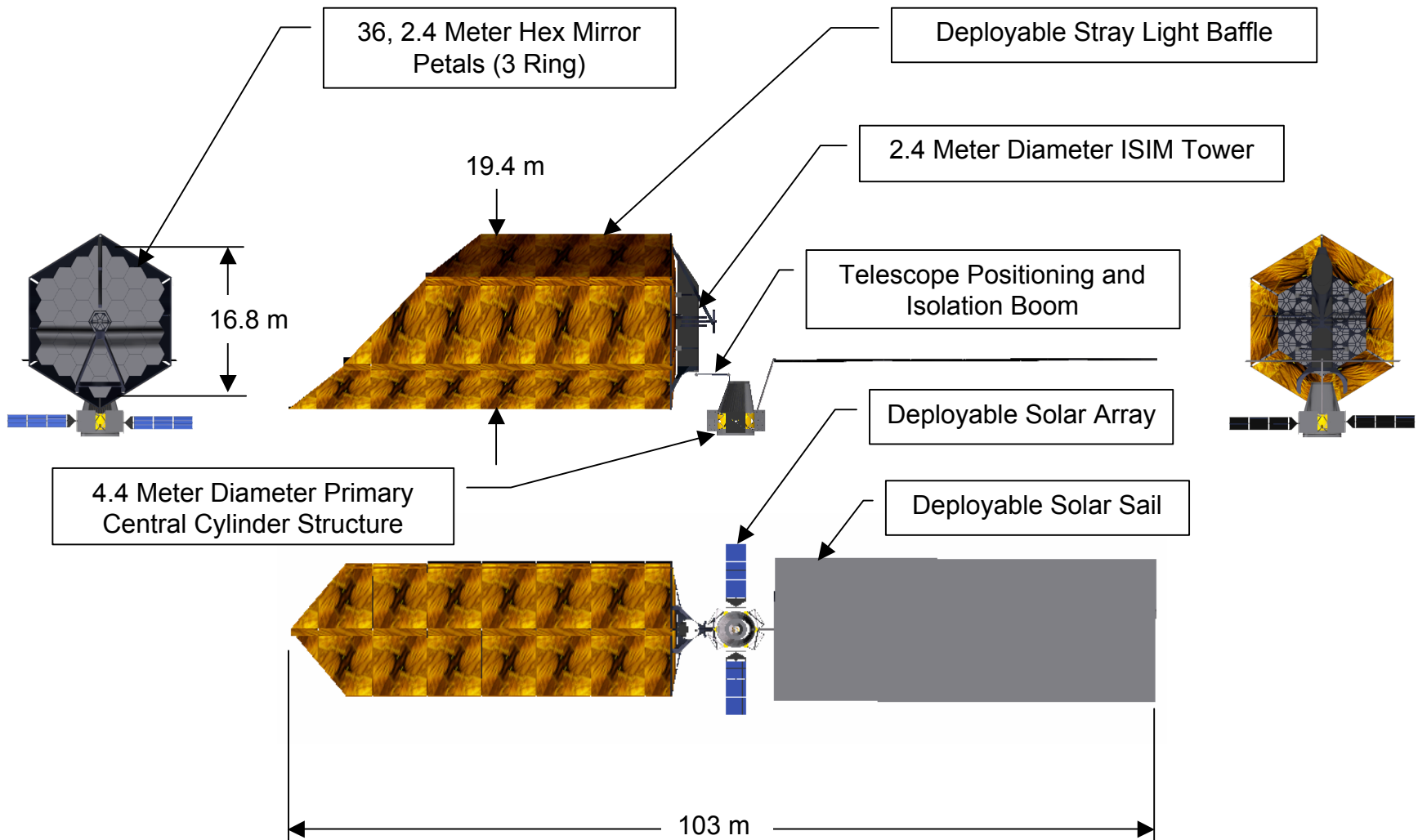
Launch Vehicle Integration & Packaging



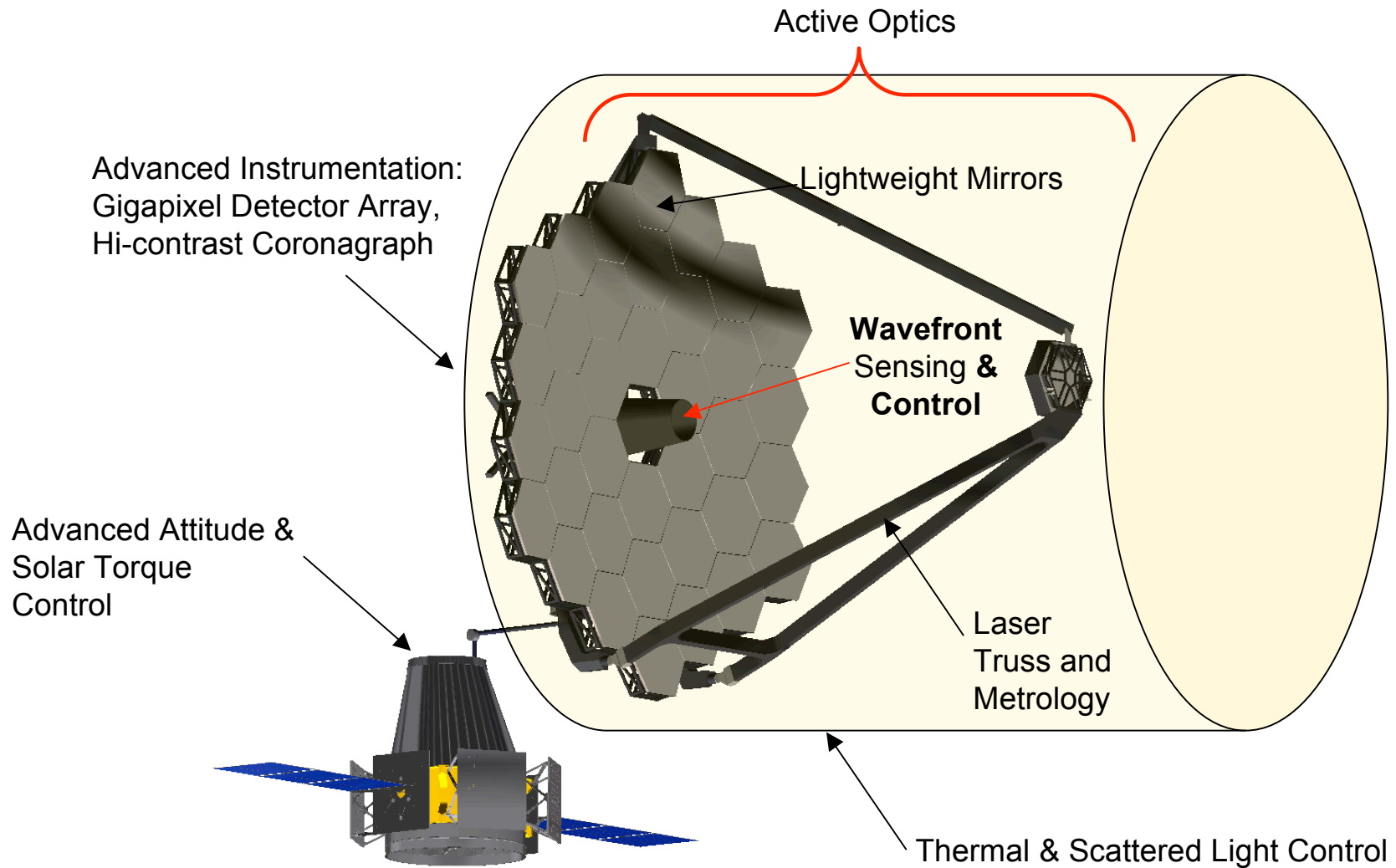
ATLAST/Ares V 16.8 m – Fold Properties



ATLAST/Ares V 16.8 m – Dimensions

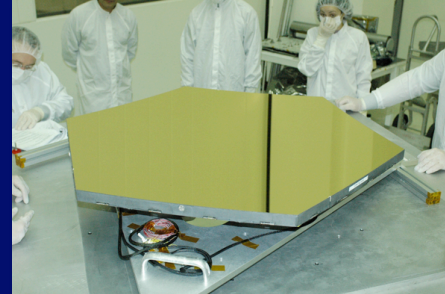


Key Technologies Needed

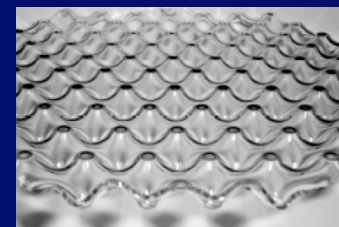
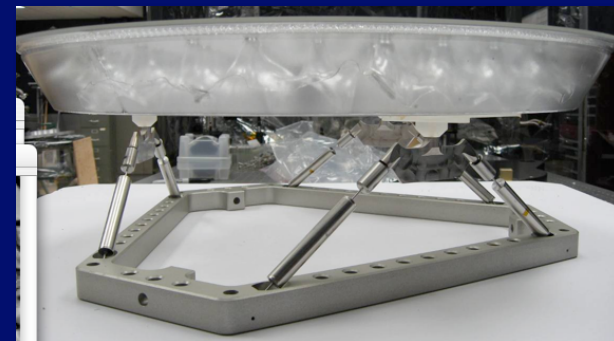


Lightweight Mirror Technology

- There are at least two potentially viable lightweight mirror technologies:
 - Nanolaminate Actuated Hybrid Mirror (AHM)
 - Corrugated Glass Mirror
- Both materials already demonstrated to achieve 8 - 12 kg/m² areal densities; lower values possible.
- 0.6 - 1.2m class mirror segments exist. Overall TRL ~ 4.
- Need to develop 2.4 - 3m class, space-qualified segment production for ATLAST



Nanolaminate materials are multi-layer metallic foils grown by sputter deposition with atomic-scale control. Current material systems have low thermal expansion and low residual thermal stress to match AHM SiC substrates thermal expansion. Final figure achieved by depositing onto inversely shaped mandrel.



Corrugated mirror made by pressing thin glass sheets into cores, then fused together.

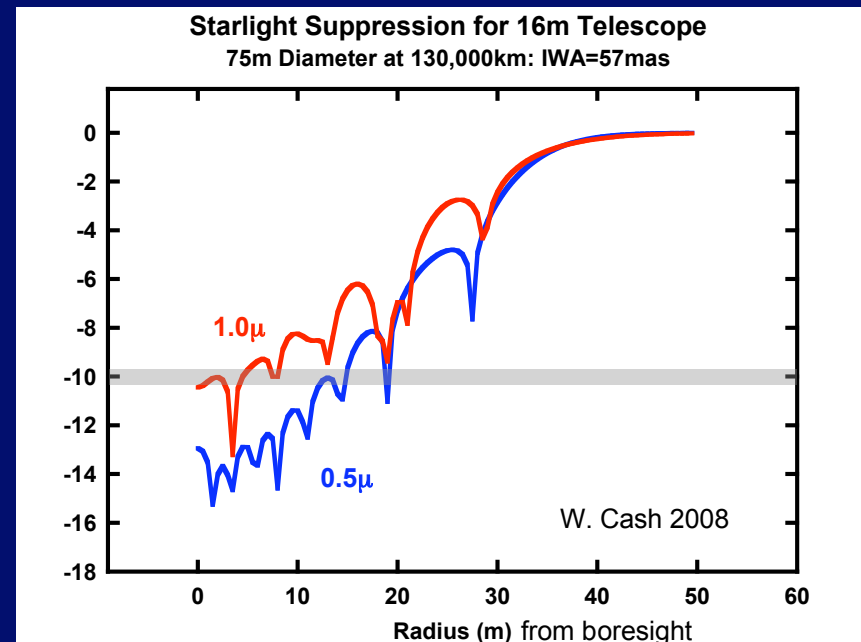
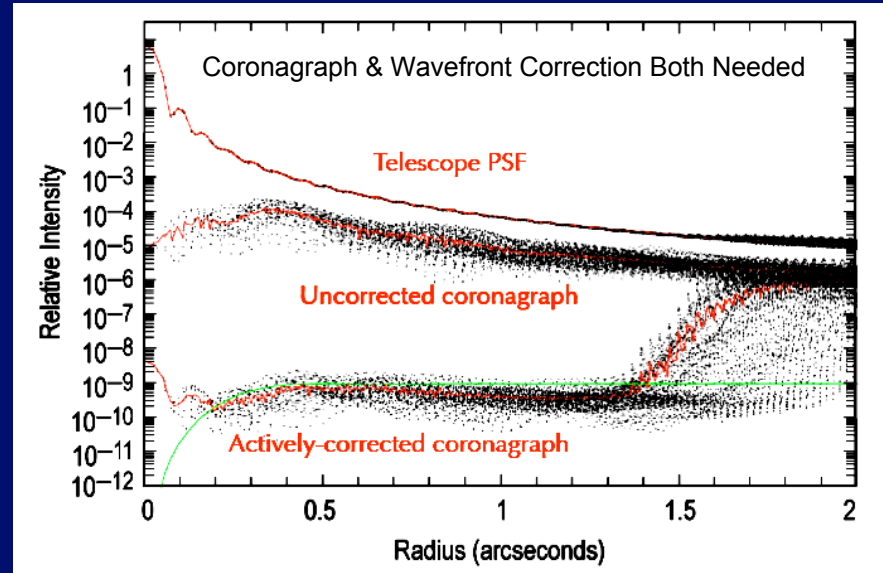
Front sheet reinforced every 5mm (no quilting); High stiffness; Slumped to near final figure.



Starlight Suppression

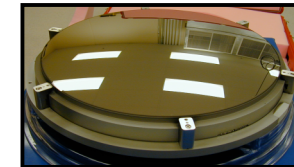
- Two basic approaches:
 - Internal coronagraph
 - External occulter
- JPL's HCIT has demonstrated sustained contrast levels of $< 10^{-9}$.
- TMT PFI proof of concept that HCI is possible with segmented optics.
- For 16-m telescope, a 75-m diameter occulter at 130,000 km enables detection of key water bands in a spectrum of a water-bearing exoplanet in HZ of solar type star at 10 - 20 pc.

1.8m telescope, contrast $1E-9$ with IWA of 0.25 arcsec. W. Traub et al.

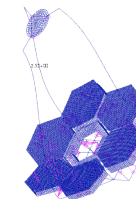
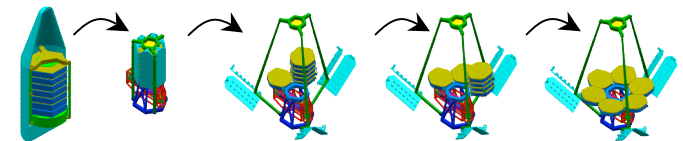
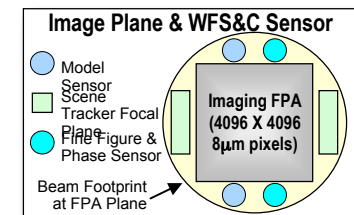
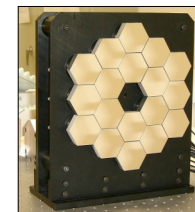
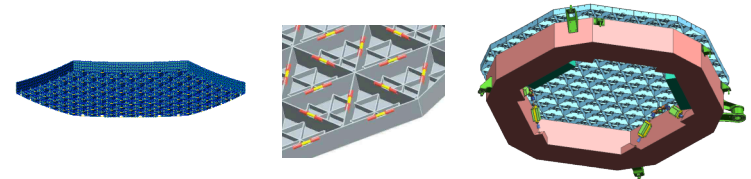


Other Technologies Enabling ATLAS-T

- Rapid, low cost fabrication of ultra-light ($< 10 \text{ kg/m}^2$) weight primary mirror segments
 - Eliminates time consuming grinding and polishing
 - Several approaches being explored
- Active figure control of primary mirror segments
 - High precision actuators
 - Surface parallel actuation eliminates need for stiff reaction structure
- High speed wavefront sensing and control
 - High density figure control enables very light weight mirror segments
 - High speed, active while imaging WFS&C allows for rapid slew and settle and earth imaging
- Scalable deployment techniques (for $>8\text{-m}$)
 - Deployment architecture should take advantage of light weight mirrors
- Active control for light weight structural elements to supply good stability
 - Reduces weight required for vibration and thermal control



Non laminate
on Mandrel



Conclusions:

- There is a strong scientific rationale for an 8-m to 16-m UV+Optical space telescope
- **Ares V greatly simplifies the design. Without Ares V:**
 - multiple launches and on-orbit assembly required for a 16-m observatory.
 - A circular, 8-m monolithic mirror would not be a viable option. An oval design would be needed, reducing resolution and sensitivity.
- A “tall” option for the Ares V fairing is needed.
- **JWST chord-fold technology can be adapted to a deployable 16-m segmented mirror but larger apertures will require a different strategy.**
- Servicing such a telescope would be highly desirable. Robotic and/or human access to E-S L2 should be developed.

